WE CLAIM:

1. A method of individually treating substrates, comprising the steps of:

(a) enclosing only one substrate within a process chamber, the process chamber proportioned to process only one substrate at a time;

(b) exposing the substrate to a chemical treatment fluid within the process chamber;

(c) after step (b), exposing the substrate to a rinse fluid within the process chamber; and

(d) after step (c), exposing the substrate to a drying vapor within the process chamber.

2. The method of claim 1, wherein step (b) includes the step of thinning a boundary layer of fluid at the substrate surface.

3. The method of claim 2 wherein the chemical treatment fluid is an etching fluid.

4. The method of claim 3 wherein the step of thinning the boundary layer includes the step of creating turbulence within the etching fluid in the chamber.

5. The method of claim 4 wherein the chamber includes a wall having varying topography, and wherein the step of creating turbulence includes flowing etching fluid past the wall and the substrate.

6. The method of claim 4 wherein the step of creating turbulence includes directing megasonic energy into the etching fluid in the chamber.

7. The method of claim 4 wherein the step of creating turbulence includes directing etching fluid into the chamber in a direction transverse to the orientation of the substrate.

8. The method of claim 3 wherein the etching fluid includes at least one of the group of etching fluids consisting of hydrofluoric acid, ammonium fluoride, and buffered oxide.

9. The method of claim 3 further including the step of removing the bulk etching fluid from the chamber.

10. The method of claim 9 wherein the chamber includes a container fluidly coupled to the chamber, and wherein the removing step includes suctioning the etching fluid into the container.

11. The method of claim 10 wherein prior to the suctioning step the container is sealed and maintained at a negative pressure, and wherein the removing step includes opening a valve between the chamber and the container, causing the etching fluid to be drawn into the container.

12. The method of claim 9 wherein the removing step includes cascading rinse water through the chamber to flush out the etching fluid.

13. The method of claim 1 including the step of directing megasonic energy into rinse fluid in the chamber during the rinsing step.

14. The method of claim 13 wherein the directing step includes forming a band of megasonic energy propagating towards a surface of the substrate, and wherein the method further includes moving the substrate through the band in an edgewise direction to cause substantially the entire surface of the substrate to pass through the band.

15. The method of claim 14 wherein the megasonic energy induces thinning of a boundary layer on the portion of the substrate passing through the band.

16. The method of claim 14 wherein during step (c) a lower region of the chamber contains rinse fluid and an upper region of the chamber contains gas, wherein the band is adjacent to a gas-liquid interface between the rinse fluid and gas.

17. The method of claim 14 wherein the substrate includes a face having a surface area, and wherein approximately 30 % or less of the surface area of the face is positioned within the band during the moving step.

18. The method of claim 14, wherein the moving step includes passing the substrate through the band a plurality of times.

19. The method of claim 16 wherein the moving step includes passing the substrate through the gas-liquid interface into the upper region of the chamber.

20. The method of claim 19, including passing the substrate through the gas-liquid interface a plurality of times.

21. The method of claim 19 further including the step of directing rinse water onto a portion of the substrate within the upper region of the chamber.

22. The method of claim 14 wherein the megasonic energy is propagated in a direction normal to the substrate surface.

23. The method of claim 14 wherein the megasonic energy is propagated at an angle that is less than normal to the substrate surface.

24. The method of claim 1 wherein step (b) includes exposing the substrate to a cleaning fluid in the chamber.

25. The method of claim 24, further including directing megasonic energy into the cleaning fluid, forming a band of megasonic energy propagating towards a surface of the substrate, and wherein the method further includes moving the substrate through the band in an edgewise direction to cause substantially the entire surface of the substrate to pass through the band.

26. The method of claim 25, wherein the moving step includes passing the substrate through the band a plurality of times.

27. The method of claim 25 wherein the megasonic energy induces thinning of a boundary layer on the portion of the substrate passing through the band.

28. The method of claim 25 wherein during step (c) a lower region of the chamber contains cleaning fluid and an upper region of the chamber contains gas, wherein the band is adjacent to a gas-liquid interface between the cleaning fluid and gas.

29. The method of claim 25 wherein the substrate includes a face having a surface area, and wherein approximately 30 % or less of the surface area of the face is positioned within the band during the moving step.

30. The method of claim 28 wherein the moving step includes passing the substrate through the gas-liquid interface into the upper region of the chamber.

31. The method of claim 30, including passing the substrate through the gas-liquid interface a plurality of times.

32. The method of claim 25 wherein the megasonic energy is propagated in a direction normal to the substrate surface.

33. The method of claim 25 wherein the megasonic energy is propagated at an angle that is less than normal to the substrate surface.

34. The method of claim 25, further including the step of causing cleaning fluid to flow through the chamber.

35. The method of claim 34, wherein the cleaning fluid flows from a bottom portion of the chamber to an upper portion of the chamber.

36. The method of claim 28, wherein the megasonic energy induces microcavitation in the band, and wherein the method further includes diffusing a gas into the cleaning fluid at the gas-liquid interface to increase the rate of microcavitation in the band.

37. The method of claim 25, further including inducing acoustic streaming within the cleaning fluid by imparting megasonic energy into the cleaning fluid in a region beneath the band.

38. The method of claim 24 wherein the method further includes exposing the substrate to an etching fluid in the chamber.

39. The method of claim 1 wherein the drying step includes removing bulk fluid from the chamber, and introducing a drying vapor into the chamber.

40. The method of claim 1 wherein, during the drying step a lower region of the chamber contains rinse fluid, and wherein the drying step includes forming an atmosphere of drying vapor in an upper region in the chamber, and withdrawing the substrate from bulk fluid in a lower region of the chamber into the upper region of the chamber.

41. The method of claim 40 further including directing megasonic energy into the rinse fluid, forming a band of megasonic energy propagating towards a surface of the substrate, wherein the withdrawing step causes the substrate to pass through

the band, and wherein the megasonic energy induces thinning of a boundary layer on the portion of the substrate passing through the band.

42. The method of claim 41 wherein the withdrawing step is performed at a rate of approximately 8 – 30 mm/sec.

43. The method of claim 41 wherein the megasonic energy is propagated in a direction normal to the substrate surface.

44. The method of claim 41 wherein the megasonic energy is propagated at an angle that is less than normal to the substrate surface.

45. The method of claim 40 wherein the withdrawing step is performed slowly, causing removal of fluid from the substrate surface using a surface tension gradient.

46. The method of claim 45 wherein the withdrawing step is performed at a rate of approximately 0.25 - 5 mm/sec.

47. The method of claim 1 wherein the drying step includes the steps of exposing the substrate to a process fluid in the chamber, performing a quick dump to discharge the process fluid from the chamber, leaving residual process fluid on the surface of the substrate, and after discharging the process fluid from the chamber, introducing a drying vapor into the system, the drying vapor condensing on the surface of the substrate and reducing the surface tension of the residual process fluid, causing the residual process fluid to flow off of the surface.

48. The method of claim 47 wherein the quick dump discharges the process fluid in less than approximately 5 seconds.

49. The method of claim 47 wherein the drying vapor includes isopropyl alcohol vapor.

50. The method of claim 47 further including the step of introducing a heated gas into the chamber to volatilize condensed drying vapor from the surface of the substrate.

51. The method of claim 1 wherein step (b) includes exposing the substrate to an etching fluid, and wherein the method further includes the step of exposing the substrate to a cleaning fluid.

52. The method of claim 50 wherein the step of exposing the substrate to a cleaning fluid is performed after step (c) and before step (d).

53. The method of claim 52, further including the step of rinsing cleaning fluid from the substrate prior to step (d).

54. A method of treating and drying a substrate, the method comprising the steps of:

(a) providing a chamber proportioned to process only a single substrate, the chamber including a lower portion and an upper portion;

(b) exposing a single substrate to a process fluid in the lower portion of the chamber;

(c) directing megasonic energy into the process fluid,

(d) forming an atmosphere of drying vapor in an upper region in the chamber;

(e) during step (c), withdrawing the substrate from the process fluid in a lower region of the chamber into the upper region of the chamber, wherein the megasonic energy induces thinning of a boundary layer on the substrate.

55. The method of claim 54 wherein step (c) forms a band of megasonic energy propagating towards a surface of the substrate, wherein the withdrawing step causes the substrate to pass through the band, and wherein the megasonic energy

induces thinning of a boundary layer on the portion of the substrate passing through the band.

56. The method of claim 55 wherein the withdrawing step is performed at a rate of approximately 8 – 30 mm/sec.

57. The method of claim 56 wherein the megasonic energy is propagated in a direction normal to the substrate surface.

58. The method of claim 56 wherein the megasonic energy is propagated at an angle that is less than normal to the substrate surface.

59. The method of claim 54 further including, after step (e), introducing a heated gas into the chamber to evaporate condensed drying vapor from the surface of the substrate.

60. The method of claim 59 wherein the heated gas is introduced through one or more inlets into the chamber, and wherein the method further includes translating the substrate past the inlets to accelerate evaporation.

61. A method of drying a substrate, the method comprising the steps of:

(a) providing a chamber proportioned to process only a single substrate;

(b) exposing a single substrate to a process fluid in the chamber;

(c) performing a quick dump to discharge the process fluid from the chamber, leaving residual process fluid on the surface of the substrate; and

(d) after discharging the process fluid from the chamber, introducing a drying vapor into the system, the drying vapor condensing on the surface of the substrate and reducing the surface tension of the residual process fluid, causing the residual process fluid to flow off of the surface.

62. The method of claim 61 wherein step (a) provides a system including a chamber, and wherein the method further includes the step of exhausting the drying vapor from the system after step (d).

63. The method of claim 61 wherein the quick dump discharges the process fluid in less than approximately 5 seconds.

64. The method of claim 61 wherein the drying vapor includes isopropyl alcohol vapor.

65. The method of claim 61 further including the step of introducing a heated gas into the chamber to volatilize condensed drying vapor from the surface of the substrate.

66. The method of claim 61 wherein the drying vapor introduced in step (d) condenses on substantially the entire surface of the object.

67. The method of claim 65 wherein the heated gas is introduced through one or more inlets into the chamber, and wherein the method further includes translating the substrate past the inlets to accelerate evaporation.

68. An apparatus for individually treating substrates, comprising:
a process chamber proportioned to process only one substrate at a time;
a source of chemical treatment fluid fluidly coupled to the process chamber;
a source of rinse fluid fluidly coupled to the process chamber; and
a source of drying vapor fluidly coupled to the process chamber.

69. The apparatus of claim 68, further including means for thinning a boundary layer of fluid at the substrate surface when the substrate is disposed in a fluid within the chamber.

70. The apparatus of claim 69 wherein the means for thinning the boundary layer includes means for creating turbulence within fluid in the chamber.

71. The apparatus of claim 70 wherein the means for creating turbulence includes a chamber and an inlet in the chamber for flowing fluid past the wall and the substrate.

72. The apparatus of claim 70 wherein the means for creating turbulence includes a megasonic transducer positioned to direct megasonic energy into fluid in the chamber.

73. The apparatus of claim 70 wherein the means for creating turbulence includes an inlet in the chamber oriented to direct fluid into the chamber in a direction transverse to the orientation of the substrate.

74. The apparatus of claim 68 further including a sealed negative pressure container coupled to the chamber, and a closed valve between the chamber and the container, the valve moveable to an opened position to cause suction of fluid from the chamber into the container.

75. The apparatus of claim 74 including a second sealed negative pressure container coupled to the chamber, and a second closed valve between the chamber and the container, the second valve moveable to an opened position to cause suction of fluid from the chamber into the second container.

76. The apparatus of claim 68 including at least one megasonic transducer positioned to direct megasonic energy into fluid in the chamber.

77. The apparatus of claim 76 wherein the megasonic transducer is oriented to form a band of megasonic energy propagating towards a surface of a substrate in the chamber, and wherein the apparatus further includes an end effector moveable

between upper and lower regions of the chamber for moving the substrate through the band in an edgewise direction to cause substantially the entire surface of the substrate to pass through the band.

78. The apparatus of claim 77 wherein the megasonic energy induces thinning of a boundary layer on the portion of the substrate passing through the band.

79. The apparatus of claim 77 wherein the lower region of the chamber is configured to contain a fluid and the upper region of the chamber is configured to contain gas, and wherein the band is adjacent to a gas-liquid interface between the rinse fluid and gas.

80. The apparatus of claim 77 wherein the substrate includes a face having a surface area, and wherein the band is proportioned such that a maximum of approximately 30 % or less of the surface area of the face is positioned within the band when the substrate passes through the band.

81. The apparatus of claim 77, wherein the end effector is configured to move the substrate through the band a plurality of times.

82. The apparatus of claim 79 wherein the end effector is configured to pass the substrate through the gas-liquid interface into the upper region of the chamber.

83. The apparatus of claim 79, wherein the end effector is configured to pass the substrate through the gas-liquid interface a plurality of times.

84. The apparatus of claim 82 wherein the chamber further includes a source of rinse water fluidly coupled to the upper region of the chamber, the source configured to direct rinse water onto a portion of the substrate within the upper region of the chamber.

85. The apparatus of claim 77 wherein the megasonic transducer is oriented to propagate energy in a direction normal to the substrate surface.

86. The apparatus of claim 77 wherein the megasonic energy is oriented to propagate energy at an angle that is less than normal to the substrate surface.

87. The apparatus of claim 68 wherein the chemical treatment solution is a cleaning solution.

88. The apparatus of claim 68 wherein the chemical treatment solution is an etch solution.

89. The apparatus of claim 88 wherein the etch solution includes at least one etching fluid from the group consisting of hydrofluoric acid, ammonium fluoride, and buffered oxide.

90. The apparatus of claim 79, wherein the megasonic transducer is further configured to induce microcavitation in the band, and wherein the apparatus further includes a source of gas fluidly coupled to the chamber and a gas outlet in the chamber, the gas outlet positioned to diffuse gas into the cleaning fluid at the gas-liquid interface to increase the rate of microcavitation in the band.

91. The apparatus of claim 77, further including a second megasonic transducer positioned to direct megasonic energy into fluid in the chamber in a region beneath the band.

92. The apparatus of claim 91 wherein the second megasonic transducer is configured to induce acoustic streaming in the fluid.

93. The apparatus of claim 68 wherein the source of drying vapor directs drying vapor into an upper region of the chamber, and wherein the end effector is

configured to withdraw the substrate from fluid in a lower region of the chamber into drying vapor in the upper region of the chamber.

94. The apparatus of claim 93 wherein the end effector is configured to withdraw the substrate at a rate of approximately 8 – 30 mm/sec.

95. The apparatus of claim 93 wherein the end effector is configured to withdraw the substrate at a rate of approximately 0.25 - 5 mm/sec.

96. The apparatus of claim 68 wherein, further including a drain configured to perform a quick dump to discharge rinse fluid from the chamber, leaving residual process fluid on the surface of the substrate, wherein the source of drying vapor is for introducing a drying vapor into the chamber after a quick dump has been performed, such that the drying vapor condenses on the surface of the substrate and reduces the surface tension of the residual process fluid, causing the residual process fluid to flow off of the surface.

97. The apparatus of claim 96 wherein the quick dump discharges the process fluid in less than approximately 5 seconds.

98. The apparatus of claim 68 wherein the drying vapor includes isopropyl alcohol vapor.

99. The apparatus of claim 68 further including a source of a heated gas fluidly coupled to the chamber to evaporate condensed drying vapor from the surface of the substrate.

100. The apparatus of claim 99, further including an outlet in the chamber for directing the heated gas in the chamber, and an end effector moveable to translate the substrate past the outlet to accelerate evaporation.

101. The apparatus of claim 68 wherein the source of chemical treatment fluid includes a source of etch fluid, and wherein the apparatus further includes a source of cleaning fluid fluidly coupled to the chamber.

102. The apparatus of claim 68 wherein the chamber includes a substrate-receiving member having a notch proportioned to receive a lower edge of a substrate, and wherein the apparatus further includes:

an end effector including a pair of substrate-receiving members, each substrate-receiving member having at least one stabilizing element and at least one engaging element, the end effector being moveable between

a first position within the process chamber wherein a lower edge of a substrate is in contact with the notch and wherein each stabilizing element is positioned at a lateral edge of the substrate to restrict movement of the substrate; and

a second position wherein the lower edge of the substrate is withdrawn from contact with the notch and wherein each engaging element supports a lateral edge of the substrate.

103. The apparatus of claim 102 wherein the at least one stabilizing element includes a slot oriented to receive a substrate edge within the slot to restrict movement of the substrate in a direction transverse to a plane containing the substrate, and a stabilizing member extending towards a substrate edge to restrict movement of the substrate in a lateral direction.

104. An apparatus for treating and drying a substrate, the apparatus comprising:

a chamber proportioned to process only a single substrate at a time, the chamber including a lower portion and an upper portion;

a source of a process fluid fluidly coupled to the lower portion of the chamber;

a source of drying vapor fluidly coupled to an upper portion of the chamber, to create an atmosphere of drying vapor in the upper portion;

an end effector having a substrate-receiving member moveable between the lower portion of the chamber and the upper portion of the chamber, said end effector operable to withdraw a substrate from process fluid in the lower portion into the atmosphere of drying vapor in the upper portion; and

a megasonic transducer positioned to direct megasonic energy into process fluid in the chamber, wherein the megasonic energy induces thinning of a boundary layer on the substrate as the substrate is moved from the process fluid into the atmosphere of drying vapor.

105. The apparatus of claim 104 wherein the transducer is position to form a band of megasonic energy propagating towards a surface of the substrate, wherein the end effector is positioned to move the substrate through the band, and wherein the megasonic energy induces thinning of a boundary layer on the portion of the substrate passing through the band.

106. The apparatus of claim 105 wherein the end effector is configured to withdraw the substrate through the band at a rate of approximately 8 – 30 mm/sec.

107. The apparatus of claim 104 wherein the megasonic transducer is oriented to propagate energy in a direction normal to the substrate surface.

108. The method of claim 104 wherein the megasonic transducer is oriented to propagate energy at an angle that is less than normal to the substrate surface.

109. The apparatus of claim 104 further including a source of heated gas fluidly coupled to the chamber to volatilize condensed drying vapor from a surface of a substrate.

110. The apparatus of claim 109, further including one or more inlets in the chamber for introduction of the heated gas into the chamber, and an end effector

having a substrate-receiving portion moveable to translate a substrate past the inlets to accelerate evaporation.

111. The apparatus of claim 104 wherein the drying vapor includes isopropyl alcohol.

112. The apparatus of claim 104 wherein the apparatus includes a system, the chamber forming a part of the system, and wherein the apparatus further includes means for exhausting drying vapor from the system.

113. An apparatus for drying a substrate, the apparatus comprising:

a chamber proportioned to process only a single substrate at a time;

a source of process fluid fluidly coupled to the chamber to immerse a substrate in process fluid;

a dump opening formed in a lower portion of the vessel and a dump door moveable between an opened condition permitting discharge of fluid through the dump opening and a closed condition sealing the dump opening, the dump door operable to evacuate a volume of process fluid immersing the substrate in approximately 5 seconds or less, leaving residual process fluid on the surface of a substrate positioned within the vessel, and

a source of drying vapor fluidly coupled for introduction into the chamber, said drying vapor selected to condense on the surface of the substrate and to reduce the surface tension of residual process fluid on the surface, causing the residual process fluid to flow off of the surface.

114. The apparatus of claim 113 wherein the apparatus includes a system, the chamber forming a part of the system, and wherein the apparatus further includes means for exhausting drying vapor from the system.

115. The apparatus of claim 113 wherein the drying vapor includes isopropyl alcohol vapor.

116. The apparatus of claim 113 further including a source of heated gas fluidly coupled the chamber to volatilize condensed drying vapor from a surface of a substrate.

117. The apparatus of claim 116, further including one or more inlets in the chamber for introduction of the heated gas into the chamber, and an end effector having a substrate-receiving portion moveable to translate a substrate past the inlets to accelerate evaporation.